

# REPORT DOCUMENTATION PAGE

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MEMORANDUM FOR PRS (In-House Contractor Publication)

FROM: PROI (STINFO)

17 May 2002

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2002-114**  
David Kirtley (ERC) and John Fife (PRSS), "Modeling, Simulation, and Design of an Electrostatic Colloid Thruster" (Viewgraphs only)

**29<sup>th</sup> IEEE International Conference on Plasma Science**  
**(Banff, Alberta, Canada) (Deadline: 26 May 2002)**

(Statement A)

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity.

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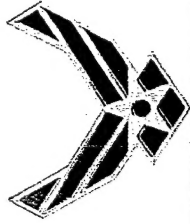
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APPROVED/APPROVED AS AMENDED/DISAPPROVED

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PHILIP A. KESSEL Date  
Technical Advisor  
Space and Missile Propulsion Division



# **Modeling, Simulation, and Design of an Electrostatic Colloid Thruster**

David Kirtley

J. M. Fife

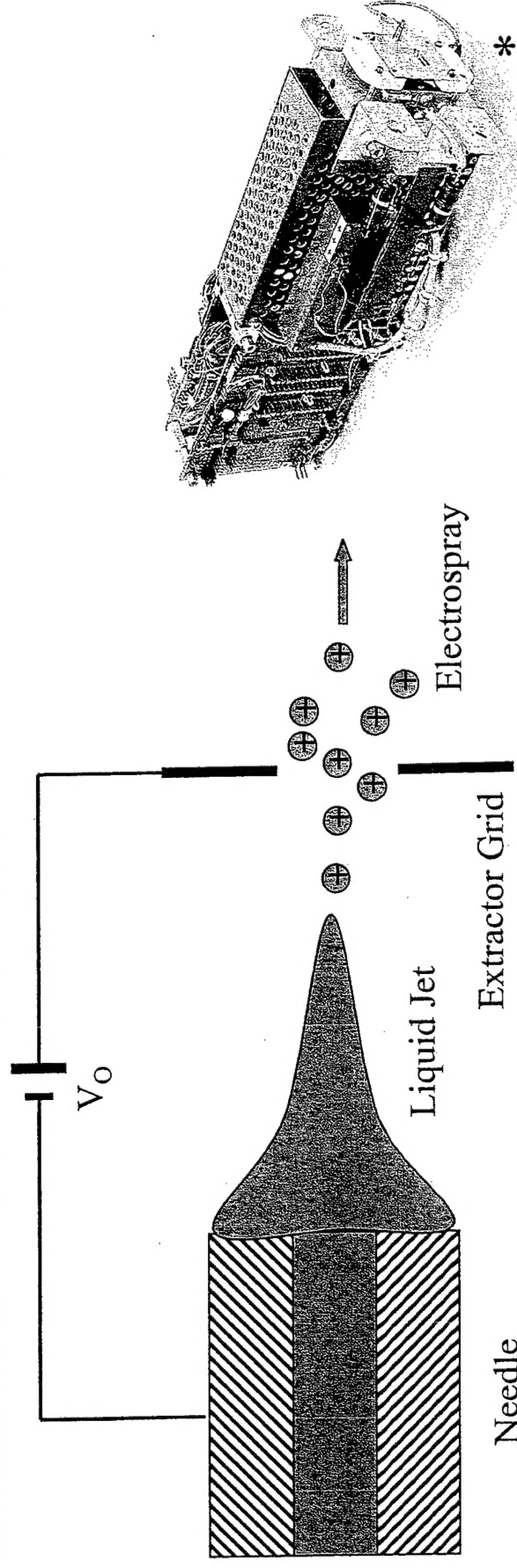
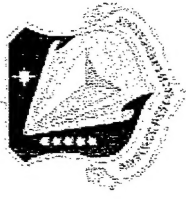
28 May 2002



- Colloid Introduction
- Design Process
  - OTS Modeling, Simulation
- Particle Tracking Analysis
- Non-Ideal Acceleration Voltages
  - Turn-On, Turn-Off, Dispersion, Off-Axis
- Preliminary Extraction Models
- Performance Optimization



# Colloid Introduction



## •Colloid Engine Theory:

- Particles with Large mass/charge enable higher thrust density Ion (electrostatic) engines
- Use electric fields to extract charged high-conductivity liquid droplets (electro-spray)
- Accelerate particles at high velocities (up to 1500s) and high efficiency (to 90%)
- Arrays of small needles that each provide small thrust ( $\mu\text{N's}$ ) with capillary feed systems
- No sheath/ionization losses/complications

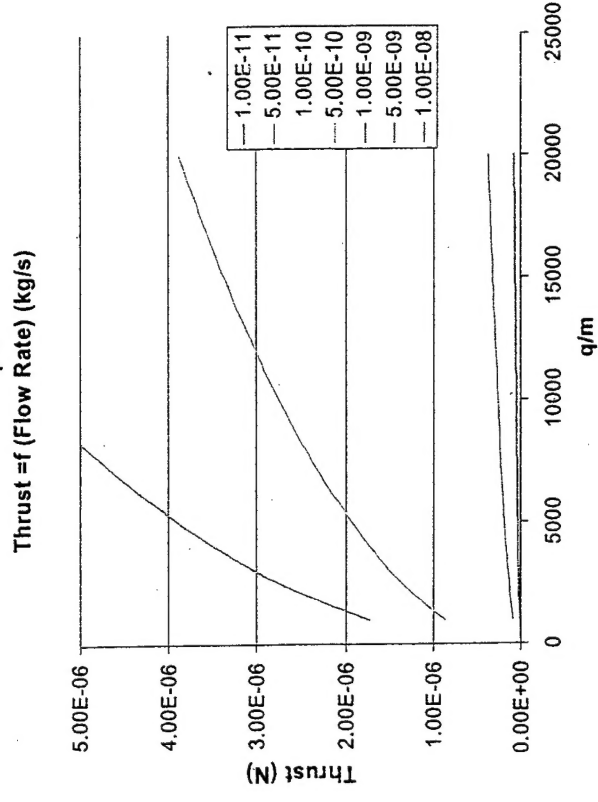
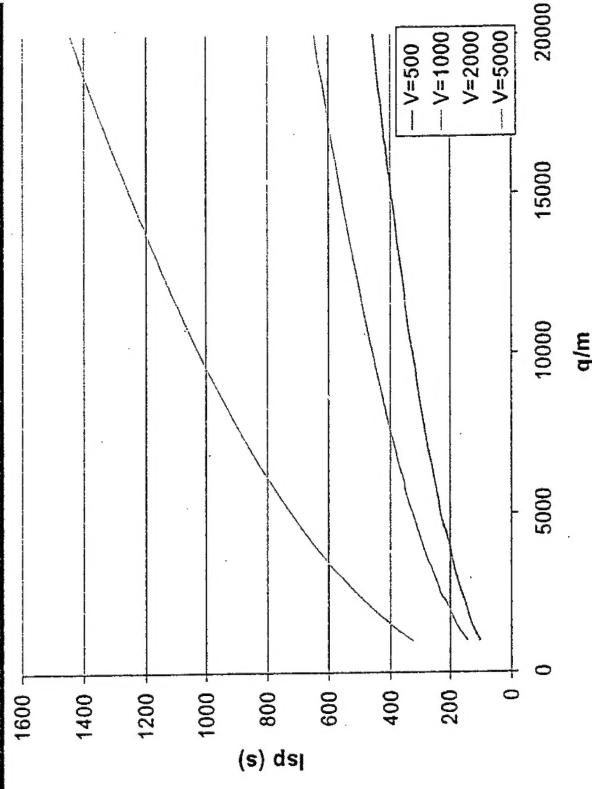


# Design Process



Design Thrusters, Not Electrospray

- Work Backwards
- Locate Missions
  - Performance Characteristics
- Design Acceleration System
  - quantify loss mechanisms
- Design Extraction System
  - Flow system, extraction voltages,
- Optimize design variables

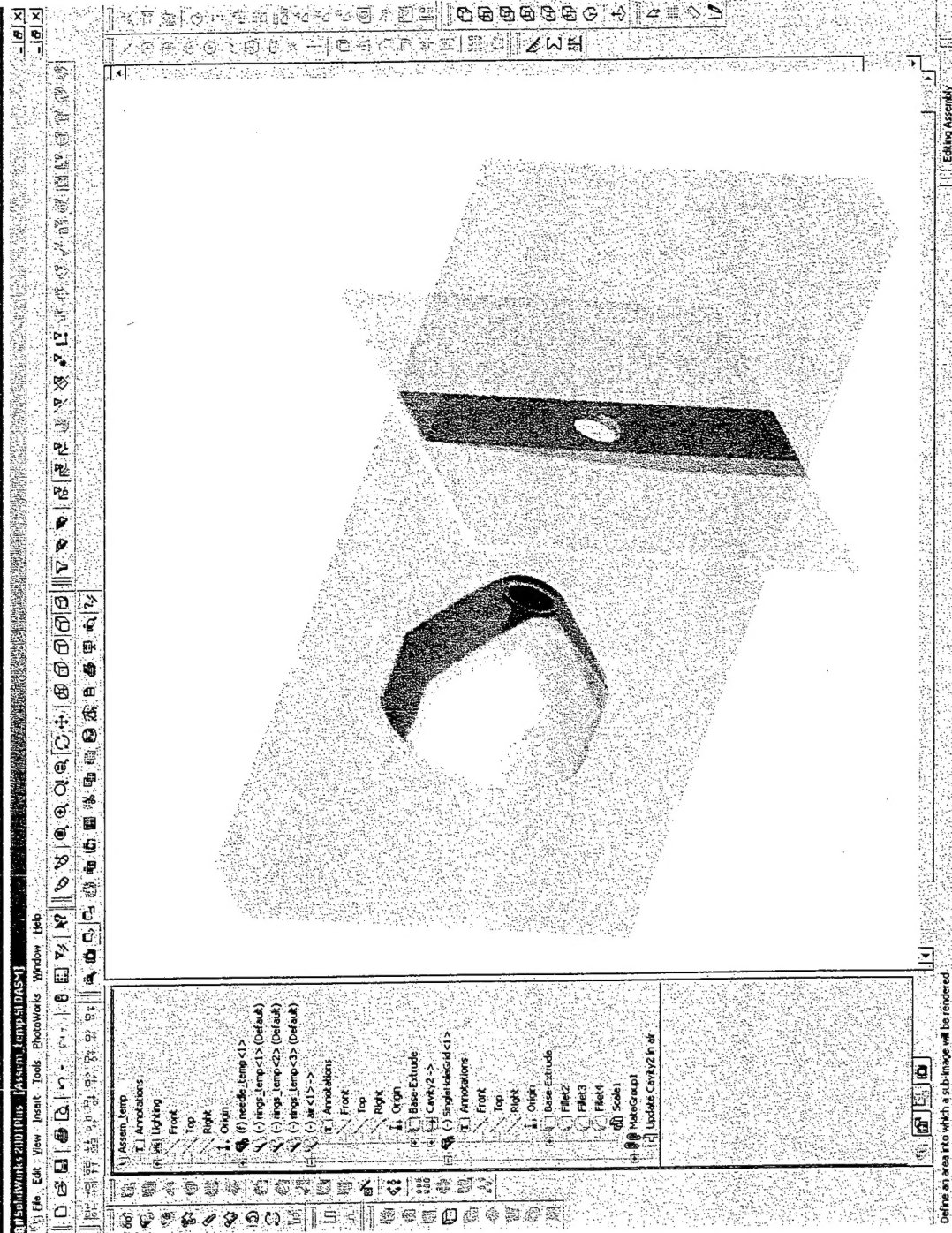




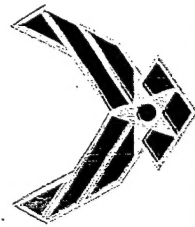
# Off-The-Shelf Modeling, Simulation



Use OTS 3D  
Modeling, Grid  
Generation,  
Electrostatic Solvers to  
speed/cheapen thruster  
design and simulation



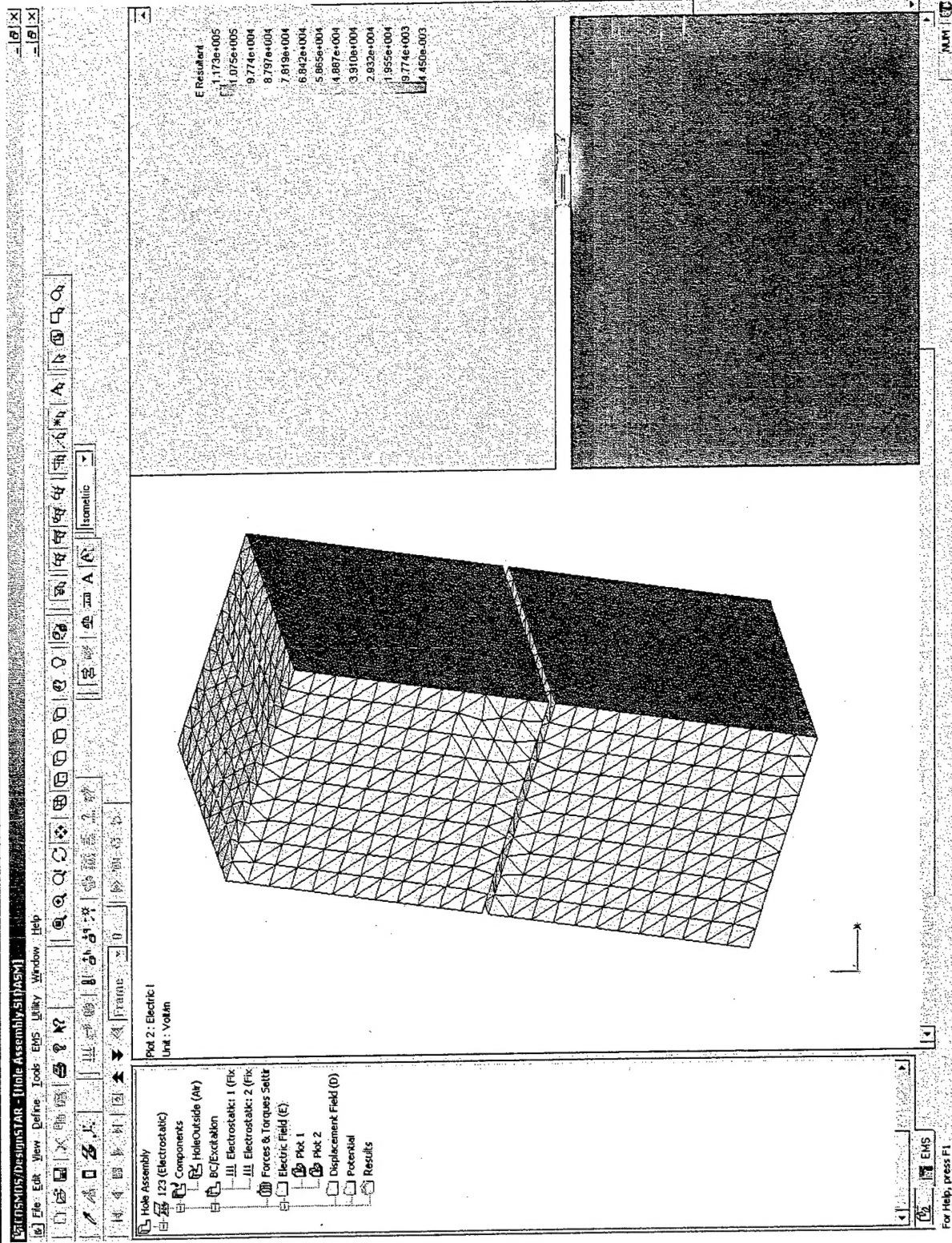
SOLIDWORKS COLLOID  
MODEL



# Off-The-Shelf Modeling, Simulation



## COSMOSWORKS EMS Gridding



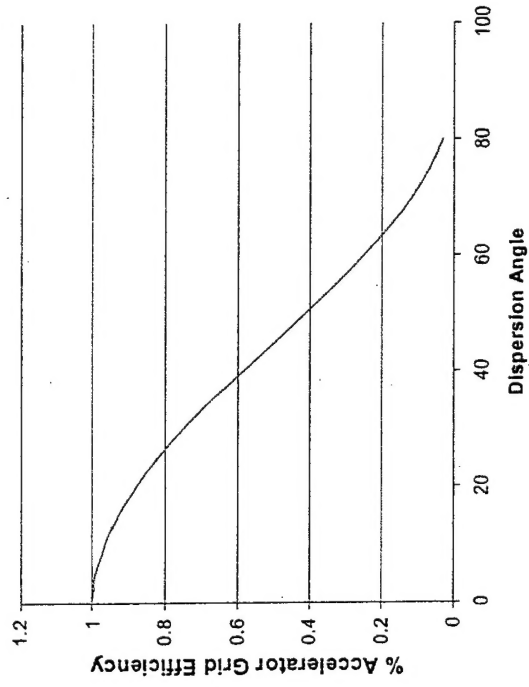
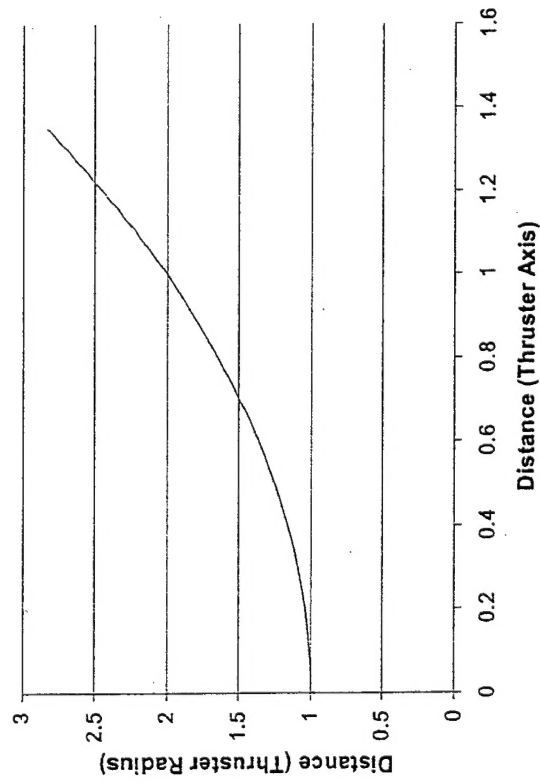


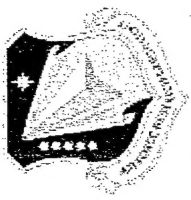
# Particle Tracking Analysis



- Straight Dispersion Prediction
- E-field shaping models
- Acceleration/Efficiency losses due to non-uniform E-fields, grids

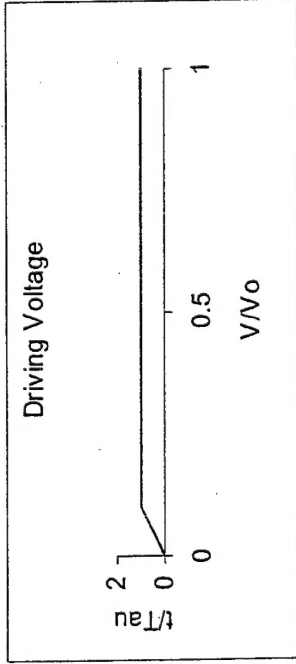
Dispersion Path





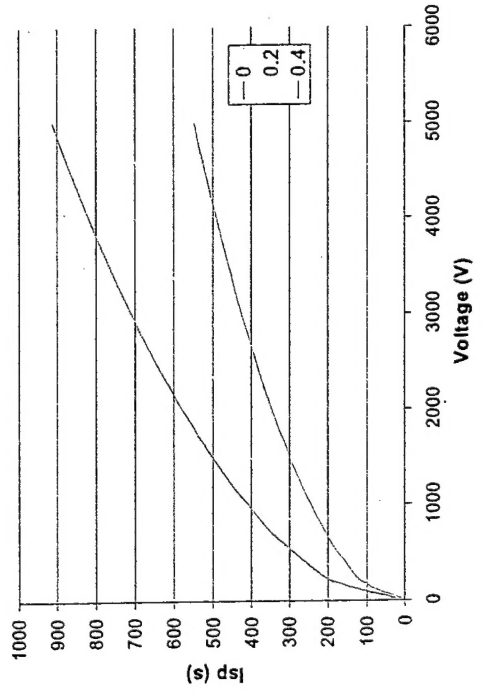
# Performance Losses

- Turn-On, single droplet



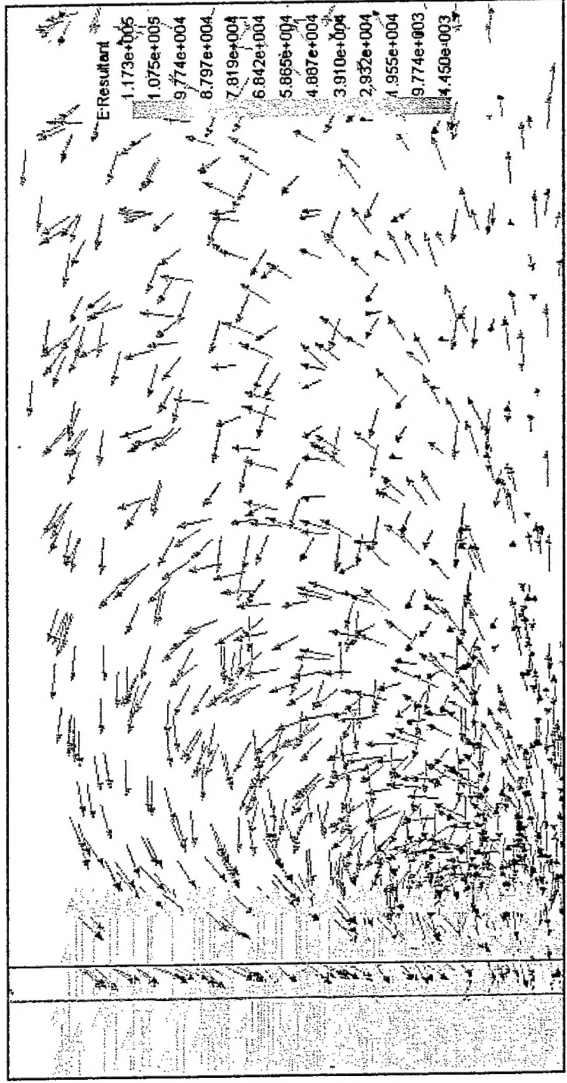
$$x(t) = \frac{q}{m} \Delta x \left( M t_{rise}^2 * t + V \left( \frac{t^2}{2} - t * t_{rise} \right) \right)$$

Isp-V as a function of Rise Time



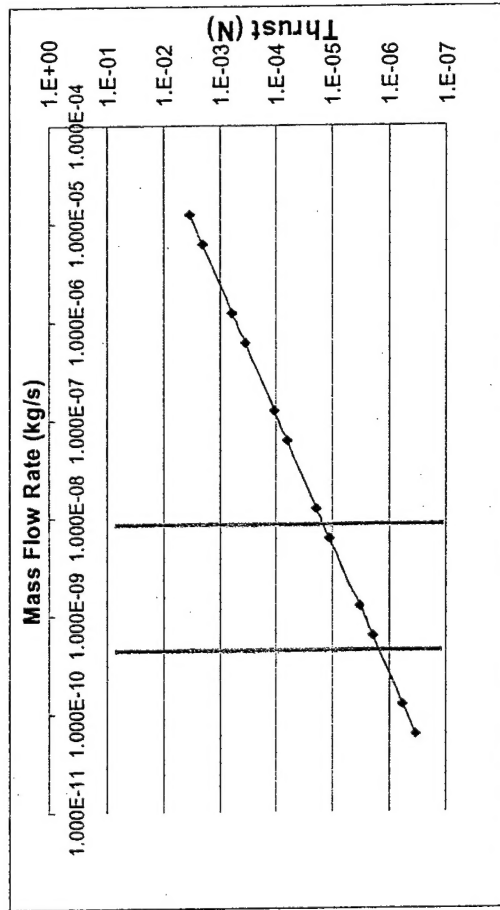
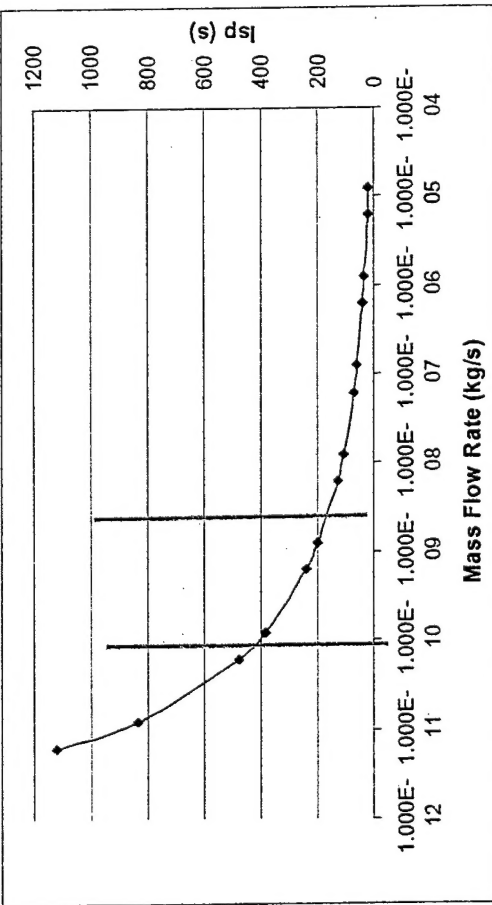
- E-field Incongruities at Interface

- Highly situation dependent
- Developed analysis system for individual cases





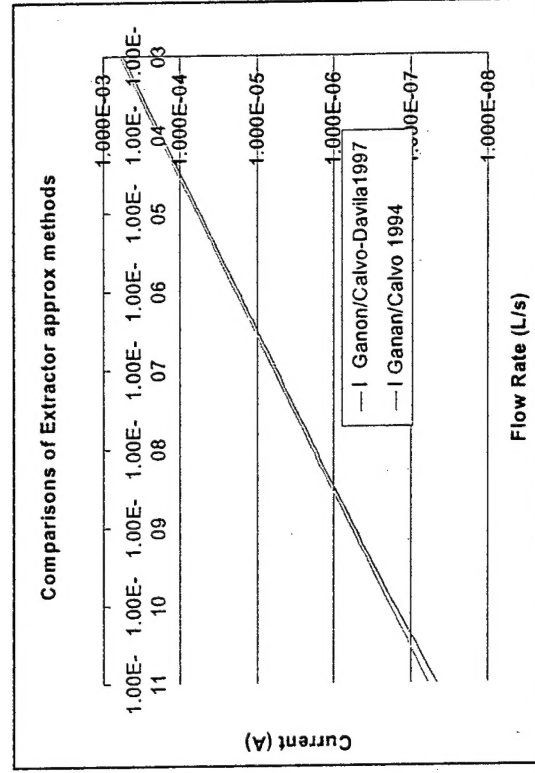
# Extractor Modeling



Ganan-Calvo 1997, 1994  
De La Mora and Loscertales 1993

$$\frac{I}{I_0} = 6.2 \left[ \frac{Q}{(\beta - 1)^{1/2} Q_0} \right]^{-2.0}$$

$$\frac{d}{d_0 (\beta - 1)^{1/3}} = 1.6 \left[ \frac{Q}{(\beta - 1)^{1/2} Q_0} \right]^{-1.0}$$





## Conclusion



- Presented is a modeling design process for a colloid micro-thruster
- Acceleration Grid Effects
- Extractor Grid Effects
- Performance Predicting, Optimization



# References



- \*Stanford Colloid Micro-Thrusters, Prof. Mark Cappelli et al.
- Ganan-Calvo, A.M. et al. Current and Droplet size in the Electrospaying of liquids. Scaling laws. 1996
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- Gamero-Castano and Hruby. Electrospray as a Source of Nanoparticles of Efficient Colloid Thrusters. Journal of Propulsion and Power, 2001.
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- Cloupeau and Prunet-Foch. Electrohydrodynamic-spraying functioning modes: a critical review. Journal of Aerosol Sciences, 1994.